POWER CONSUMPTION OF DOMESTIC REFRIGERATOR USING NANOPARTICLES Al_2O_3 LUBRICANT MIXTURE

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ABSTRACT

This paper studied the performance of a domestic refrigerator operating with or without nanoparticles alumina (Al_2O_3) lubricant mixture with different level of refrigerant charged into the refrigeration system. The nanoparticles Al_2O_3 lubricant mixture by volume concentration of 0.2% was prepared via two step method. The quantity of refrigerant charged by pressure was ranged from 36 psi to 44 psi. The evaluation was carry out by comparing the overall performance in term of refrigeration capacity (Q_L), compressor work (W_{in}), coefficient of performance (COP) and power consumption for both sets of experimental testing. The refrigeration system of HFC134a/Al_2O_3/POE oil works normally and safely. From the results, the refrigeration performance for experiment operating with HFC134a/Al_2O_3/POE oil system was improved compared to HFC134a/ /POE oil system. Both refrigeration systems attained its optimum level at 42 psi charging pressure. The power consumption for HFC134a/Al_2O_3/POE oil system at optimum refrigerant charged which is 42 psi was the least with value 0.32 kW/h and the highest COP of 2.67. The percentage of increment in term of COP was between 2.81%, 3.59%, 3.89%, 4.55% and 5.91%. For the power consumption, the percentage of reduction was 1.47%, 1.61%, 1.80%, 2.07% and 1.77%. Thus, the addition of Al_2O_3 nanoparticles into the base fluid (POE) for better performance and reduction of power consumption was achievable.

ABSTRAK

Tesis ini mengkaji prestasi bagi suatu peti sejuk domestik yang beroperasi dengan atau tanpa campuran nanopartikel alumina (Al_2O_3) dan minyak pelincir ke atas prestasi tahap penyejukan yang berbeza. Campuran nanopartikel Al_2O_3 dan minyak pelincir dengan kepekatan sebanyak 0.2% telah disediakan melalui kaedah dua langkah. Kuantiti penyejukan yang dicaskan dengan tekanan antara 36 psi hingga 44 psi. Penilaian telah dijalankan dengan membandingkan prestasi keseluruhan dari segi kapasiti penyejukan (Q_L), kerja pemampat (W_{in}), COP dan penggunaan kuasa elektrik bagi kedua-dua set eksperimen ini. Sistem penyejukan dengan HFC134a/Al_2O_3/POE berfungsi dengan normal dan selamat. Daripada keputusan yang diperolehi, prestasi penyejukan untuk sistem HFC134a/Al_2O_3/POE telah bertambah baik jika dibandingkan dengan system HFC134a / POE. Kedua-dua sistem penyejukan mencapai tahap yang optimum pada 42 psi. Penggunaan kuasa electrik untuk sistem HFC134a/Al_2O_3/POE dengan kuantiti penyejukan yang optimun iaitu 42 psi adalah 0.32 kW / j dan COP yang tercapai adealah tertinggi iaitu 2.67. Peratusan kenaikan untuk COP adalah di antara 2.81%, 3.59%, 3.89%, 4.55% dan 5.91%. Untuk penggunaan kuasa elektrik, peratusan pengurangan adalah 1.47%, 1.61%, 1.80%, 2.07% dan 1.77%. Oleh itu, penambahan campuran nanopartikel Al_2O_3 ke dalam bendalir asas (POE) untuk prestasi yang lebih baik dan pengurangan penggunaan kuasa electric telah tercapai.

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LIST OF SYMBOLS

Al_2O_3	Aluminium (III) Oxide / Alumina
˚c	Celsius
ρ	Density
˚F	Fahrenheit
g	gram
H_2O	Water
kJ	kilojoule
kg	kilogram
Kw/h	Kilowatt/hour
m	mass
ml	millilitre
Q_L	Refrigeration Capacity
V	volume
W_{in}	Compressor Work

LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineer
COP	Coefficient of Performance
HFC134a	Refrigerant R-134a/ 1,1,1,2-Tetrafluoroethane
POE	Poly-ol-ester Oil

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The advancements of nanotechnology have allowed the development of nanoparticles as an additive for Tetrafluorethane (HFC134a)/POE lubricant oil system which might improve the performance of refrigeration system. The nano additives can be charged into the refrigeration system via mixing nanoparticles with the existing lubricant oil. The nano additives might reduce the wear, tear and friction better than the existing lubricant oil in the compressor. Besides, the addition of nanoparticles in mineral based polyester lubricant oil can be used as to enhance the overall heat transfer performance of refrigeration system in domestic refrigerator. Recently, many researchers emphasized on the importance of nanoparticles as additives as it shows greater promise for use in cooling system such as refrigeration system.

The refrigeration systems used in domestic refrigerators mostly are of compression type system. The working principle of the vapor-compression refrigeration cycle is modified from the reversed Carnot cycle. It is a steady state refrigeration system where the refrigerant flows in one direction steadily with continuous cooling effect. The continuous improvement and modifications of the reversed Carnot cycle have resulted in the introduction of the vapor-compression refrigeration cycle and until now, the household refrigeration and air conditioning working principle is based on this cycle. Jacob Perkins, an Englishman, built a prototype of closed cycle ice machine based on the vapor compression cycle in 1834; it was commercialized by Alex Twinning in 1850 then. There are many research and experiments have been done as to enhance the overall performance of the refrigerator and cost savings.

A basic refrigeration system consists of four fundamental elements which are the compressor, condenser, expansion valve and evaporator. In real condition, the theoretical performance of refrigeration system was deteriorated due to the internal and external reversibility in the system. The internal reversibility is due to the design and selection of compressors used in the refrigerator. For the external reversibility, it is due to losses of condenser and evaporator. Therefore, the effectiveness on the functionality for each component is influencing the performance of the refrigeration system directly.

For the refrigerant compressors, they are known as the heart of the vapor-compression systems. A refrigerant compressor controls the circulation of the refrigerant by adding pressure on it. The refrigerant is compress to high pressure and high temperature from the evaporator at this stage. However, for the refrigerant compressor to be maintained in a hermetic condition, lubricant oil is necessary in lubricate the moving part in a domestic refrigerator. The quality of lubricate oil is closely associated with the lifespan of the compressor. It is because the lubricant oil is used to lubricate the internal parts of the compressor by mixing with the refrigerants employed in the refrigeration system. Commonly, mineral based oil such as polyester (POE) lubricant oil is used as to reduce wear, tear and friction on metal parts of the compressor in industrial applications. When the compressor pumps the refrigerant around the circuit, the temperature will be increased. As the temperature increases, the internal metal parts of the compressor heating up. The lubricant oil functioned as to cool down and lubricate the hot metal parts so that the compressor able to operate efficiently.

Then, the refrigerant is discharged into condenser upon completion of compression process. The condensation process rejects heat to the surroundings. The condensed refrigerant will flow into the expansion device after condensation process. The refrigerant vapour expanded as the pressure reduced. At this state, it draws the energy from surroundings or medium in contact as to produce continuous refrigerating effect. The cycle is complete when the refrigerant flows into the evaporator, from the expansion valve, as a low-pressure, low-temperature liquid.

Despite of that, the refrigerant charged into the refrigeration system is another factor that influenced the performance of refrigeration system. This parameter can be altered easily as to optimize the performance of refrigerator. Anyhow, the refrigerant charged into the refrigeration system should be kept within the compressor’s limits. It is to avoid flooding or slugging due to excessive liquid refrigerant charge in the refrigeration system.

A lot of advancement happens in our world today, a need to reduce the power consumption to lubricate the moving parts of the refrigerator using nano additives in lubricant for refrigeration system was compromised. Through the employment of HFC134a/POE oil system with nano addtives, the flow and thermal characteristics might be improved. Therefore, a reduction in energy consumption of refrigerator is possible via this heat transfer enhancement technology.

The rate and amount at which the condenser discharges the heat to the environment and also the rate and amount which the evaporator absorbs heat from the compartment can be a measure of performance and efficiency of the refrigeration system. The measure on performance and efficiency of the refrigeration system is evaluated based on the coefficient of performance, COP computed. As the COP higher, the performance of the refrigeration system better. In addition, the power consumption of the refrigerator which operating with HFC134a/POE oil system with or without nanoparticles $Al_2O_3$was analyzed based on the data recorded in Wh. The power consumption of the refrigeration system operating with HFC134a/POE oil with nanoparticles Al_2O_3 will be highlighted.

This project report is to give the basic understanding on the potential of nanoparticles Al_2O_3 as an additive in conventional HFC134a/POE oil system with different refrigerant charged.

1.2 PROBLEM STATEMENT

A refrigerator can be one of the most costly household appliances. There are several methods for mankind to reduce the electricity bills by reducing energy consumption of the domestic refrigerator such as turn off the ice maker or water dispenser, unplug the refrigerator, regular checking on worn and cracked seals and minimize the amount of times on opening the doors of the refrigerator. However, this method cannot solve the problem permanently and yet inconvenient to other parties under the same roof.

Nanotechnology has the potential to revolutionize the way we live our daily lives. It can make our life much easier. The development of nano additive to the existing refrigeration HFC134a/POE oil system might enhance heat transfer; reduce the work load of compressor and thus the amount of power consumption in the refrigeration system as well. The study needed to analyze the actual performance of present refrigeration HFC134a/POE oil system and compare it with refrigeration HFC134a/Al_2O_3/POE oil system

1.3 OBJECTIVES

The main objective of this study is:

i) To conduct an experimental testing operating on HFC134a/POE oil system with or without addition of nanoparticles Al_2O_3 with different refrigerant charged into the system
ii) To prepare nanoparticles Al_2O_3 polyester lubricant mixture
iii) To analyse the performance of HFC134a/POE oil system with or without addition of nanoparticles Al_2O_3.
iv) To compare the performance on HFC134a/POE oil system with or without addition of nanoparticles Al_2O_3.

1.4 SCOPES

i) Fundamental study of refrigeration system HFC134/POE oil system with different refrigerant charged
ii) Potential of oxide based nanoparticles Al_2O_3 (alumina) as additives in lubricant
iii) Sample preparation of nanoparticles Al_2O_3 polyester lubricant mixture via two step method

1.5 LIMITATIONS

The limitations in conducting this study included the location of the experimental test rig. The experimental testing on refrigeration system is unable to carry out in control room. Therefore, there are several environmental factors that are neglected during this experimental testing such as the surrounding temperature and humidity. Besides, the experimental testing for refrigeration system should be run for a periods of 24 hours. The experimental testing can only run for ten hours due to the restricted accessibilities of students to laboratory. The range of temperature setting for thermostat in the refrigerator is fixed at less than half of its range.

CHAPTER 2

LITERATURE REVIEW

2.1 THERMODYNAMICS LAW

The First Law of Thermodynamics asserts that energy is a thermodynamics property whereas the Second Law of Thermodynamics asserts that energy has quality as well as quantity and actual processes occur in the direction of decreasing quality of energy. However, a process cannot take place in a refrigeration system unless it satisfied both the first and second laws of thermodynamics.

As we known, the heat is transferred in the direction of decreasing temperature. The heat is transferred form high temperature mediums to low temperatures ones. The processes occur in a certain direction but not in the reverse direction. The reverse process cannot occur by itself. Therefore, the heat transfer from a low temperature medium to a high temperature one which requires special devices are called refrigerator.

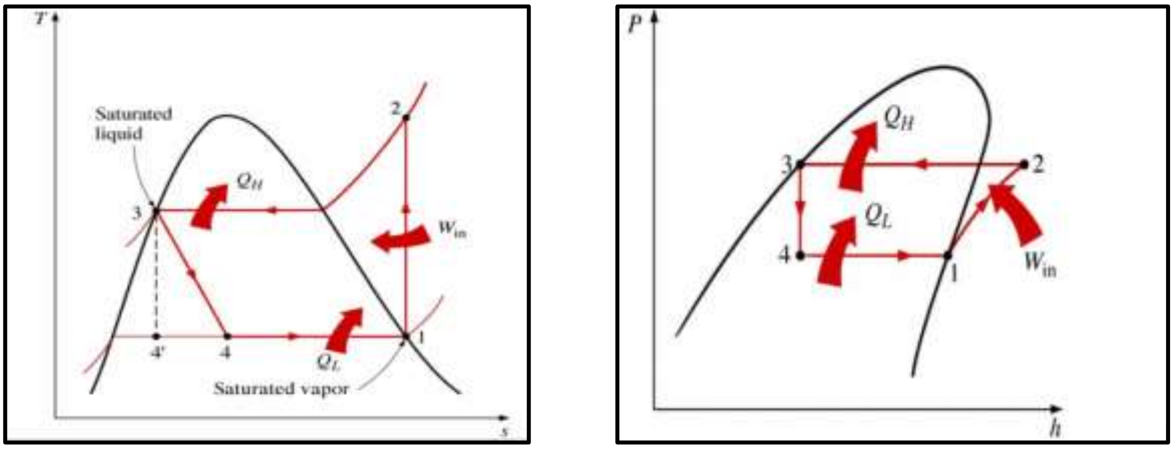
The Second Law of Thermodynamics is used in determining the theoretical limits for the performance of refrigerators. Under the Second Law of Thermodynamics, there are the Kelvin Planck and Clausius statement. For the Clausius statement which is related to refrigerators implies that it is impossible to construct a device that operates in a cycle and produces no effect other than transfer of heat from a lower temperature body to a higher temperature body (Cengel, 2007). Commonly, the heat does not naturally transfer on its own from a cold medium to a warmer one. Indirectly, the Clausius statement means if there is a cyclic device that able to produce net effect on others, the heat can be transferred from a cold medium to a warmer one. Therefore, a refrigerator must be operated with a compressor driven by an external power source. The net effect on the surroundings mentioned involves the consumption of energy in the form of work. The power consumption by the compressor work will be very useful on evaluation of the performance of refrigerator. To conclude, a domestic refrigerator is in complete compliance with the Clausius statement of the second law.

2.2 IDEAL VAPOR COMPRESSION REFRIGERATION CYCLE

Commonly, the ideal vapour-compression refrigeration cycle is employed for most refrigeration system of refrigerator. In ideal vapour-compression refrigeration cycle, the refrigerant vaporized completely in the evaporator before compression. Then, an expansion valve or capillary tube which acts as the throttling device was used to replace the turbine. There are four fundamental processes in an ideal vapour-compression refrigeration cycle where the refrigerant has to go through inside the refrigeration system.

i) Isentropic Compression in a Compressor
ii) Constant Pressure Heat Rejection in a Condenser
iii) Throttling in an Expansion Device
iv) Constant Pressure Heat Absorption in an Evaporator

Figure 2.1 is the ideal vapour compression refrigeration cycle where (a) is the temperature-entropy (T-s) diagram of the cycle and (b) is the pressure-enthalpy (p-h) diagram of the cycle.



(a) (b)

Figure 2.1: Ideal vapour compression diagram (a) T-s diagram, (b) p-h diagram

Source: Cengel 2007

In an ideal vapour compression refrigeration cycle, the refrigerant enters the compressor as saturated vapour at stage 1. Then, it is compressed isentropically to condenser pressure. During the isentropic compression process, there is an increase in the temperature of the refrigerant than that of the surrounding medium. The refrigerant enters condenser as saturated vapour at stage 2. The refrigerant leaves the condenser as saturated liquid at stage 3. The heat rejected to surroundings. The saturated liquid at stage 3 is passing through an expansion valve or capillary tube which acts as the throttling device. During this process, there is a decrease in the temperature of the refrigerant than that of the refrigerated space. At stage 4, the refrigerant enters as a low quality saturated mixture. It is completely evaporates by absorbing heat from the refrigerated space. The refrigerant will then leave the evaporator as saturated vapour and re-enters the compressor to complete the cycle.

2.3 VAPOR COMPRESSION REFRIGERATION SYSTEM

As mentioned above, in a basic vapour compression refrigeration system, there are four fundamental thermal processes take place. There are evaporation, compression, condensation and expansion. The schematic diagram of the basic vapour compression refrigeration cycle in refrigeration system is shown in Figure 2.2.

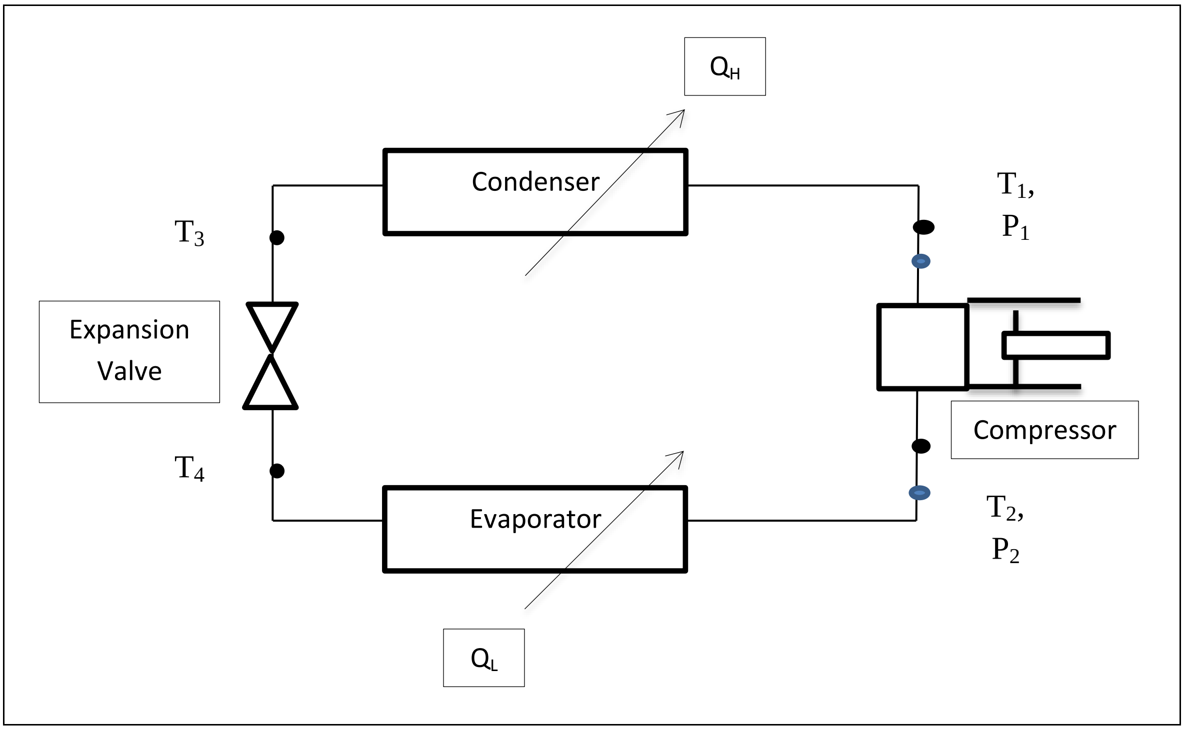


Figure 2.2: Schematic diagram of the basic vapor compression refrigeration cycle in refrigeration system

By applying steady-state flow according to the first law of thermodynamics, a vapour compression refrigeration cycle which comprises of a number of flow processes as illustrated below can be analysed (Dincer, 2003). Assume that the changes in kinetic and potential energies are negligible.

2.3.1 Evaporation Process

Evaporation is the gaseous escape of molecule from the surface of a liquid. It is accomplished by the absorption of a considerable quality of heat without any change in temperature. In the evaporator of a refrigeration system, a low pressure cool refrigerant vapor is brought into contact with the medium to be cooled, absorb heat, and hence boil, producing a low pressure saturated vapor. q_L is the heat taken from the low temperature environment to the evaporator per unit mass as expressed in Eq. (2.1). The refrigeration capacity is expressed as Eq. (2.2).

$$qL = (h1 - h4)kJ/kg \tag{2.1}$$

$$QL = m(h1 - h4)kW \quad (2.2)$$

2.3.2 Compression Process

The compressor raises the pressure of the refrigerant vapor obtained from the evaporator. The compressor work per unit mass is expressed as in Eq. (2.3). W_{in} is compressor power input, kW and expressed as in Eq. (2.4).

$$win = (h2 - h1)kJ/kg \quad (2.3)$$

$$Win = m(h2 - h1)kW \quad (2.4)$$

2.3.3 Condensation Process

Under condensation, the vapor is changed into a liquid by extracting heat. The refrigerant of high pressure and gaseous carries the heat energy absorbed in the evaporator and the work energy from the compressor into condenser. q_H is the heat rejection from the condenser to the high temperature environment per unit mass as expressed in Eq. (2.5). The heating capacity is expressed as Eq. (2.6).

$$qH = (h2 - h3)kJ/kg \quad (2.5)$$

$$QH = m(h2 - h3)kW \quad (2.6)$$

2.3.4 Throttling Process

The condensed refrigerant liquid is returned to the beginning of the next cycle. A throttling device such as expansion valve is used to reduce the pressure of the refrigerant liquid to the low pressure level and the boiling temperature of the refrigerant to below the temperature of the heat source. The enthalpy throughout the system remains as expressed in Eq. (2.7).

$$h3 = h4\ kJ/kg \tag{2.7}$$

2.3.5 Coefficient of Performance

The coefficient of performance, COP of the refrigeration system is the ratio of refrigeration effect, Q_L to the compressor work per unit mass, W_{in}. The COP is expressed as in Eq. (2.8).

$$COP = \frac{Q_L}{W_{in}} \tag{2.8}$$

2.4 ACTUAL VAPOR COMPRESSION REFRIGERATION CYCLE

An actual vapor compression refrigeration cycle differs from the idealized model due to the irreversibility that occurs in various components such as fluid friction and entropy generation in the system. The Temperature-Entropy ($T-s$) diagram of actual vapor compression refrigeration cycle is shown in Figure 2.3.

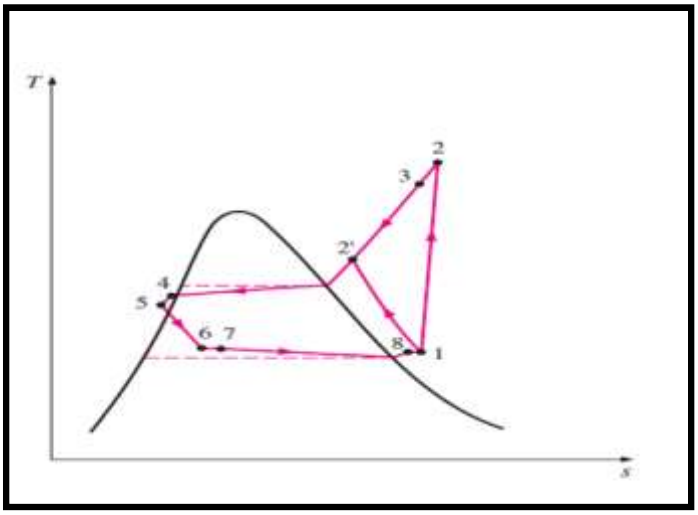


Figure 2.3: Temperature-Entropy (T-S) diagram of actual vapor compression refrigeration cycle

Source: Cengel 2007

The irreversibility that occurs in an actual vapor compression refrigeration cycle is divided into internal and external irreversibility in the system. For internal irreversibility, it is due to non-isentropic compression, friction and heat transfer to or from the surroundings. It is dependent on the selection and design of compressor used in the refrigerator. The external irreversibility is due to the losses on condenser and evaporator due to finite rate of heat exchange against finite values of temperature difference and heat capacities of external fluids. Therefore, a vapour compression refrigeration system can be optimized theoretically and balanced via finite time thermodynamics. However, a correct estimation on parameters involving in irreversibility is a real challenge.

For heat transfer coefficient on the external fluid in the evaporator and condenser, it can be optimized easily. However, for the heat transfer coefficient over the refrigerant R-134a in condenser, it is difficult. This is because they are closely associated with the phase change of refrigerant in the refrigeration system. The boiling heat transfer coefficient over the refrigerant R-134a in evaporator is hard to be estimated as well (J. K. Dabas, 2011).

2.5 COMPONENTS OF THE MECHANICAL VAPOR COMPRESSION REFRIGERATION SYSTEM

As mentioned earlier, there are four fundamental components employed in a refrigeration system. There are evaporator, compressor, condenser and capillary tube which acts the throttling device.

2.5.1 Evaporator

Evaporator divided into two main categories. There are direct cooler evaporators that cool air and in turn cool the products and indirect cooler evaporators that cool a liquid such as brine solution and in turn cool the product (Dincer, 2010).Commonly, the evaporators such as liquid coolers and air coolers or gas coolers used for cooling, refrigeration, freezing and air conditioning applications (Dincer, 2010).

2.5.2 Compressors

Generally, the compressor functioned as a mechanical device to compress and pump the refrigerant vapour from a low pressure region (the evaporator) to a high pressure region (the condenser) (M.Y.Taib). This is important in maintaining the desired temperature and pressure in the evaporator. Besides, the secondary function of the compressor within the refrigeration system is to increase the pressure and temperature of the refrigerant vapour.

There are several types of compressor used in refrigeration system such as hermetic compressors, semi-hermetic compressors, open compressors and displacement compressors.

Hermetic compressors are preferable due to its design for smaller range of temperatures required in air cooling applications primarily. Hermetic compressors are available for small capacities. The motor and drive of compressors are sealed in compact welded housing which is also where the refrigerant and lubricating oils are contained. Another advantage of hermetic compressors is it can work for a long period of time in a small-capacity refrigeration system without any maintenance requirement and without any gas leakage. Besides, it is sensitive to electric voltage fluctuations which may make the copper coils of the motor burn. The hermetic type compressors are widely used in domestic refrigerator, freezers and air conditioners (Dincer, 2010). Figure 2.4 is the cut-in view of the hermetic typed compressor.

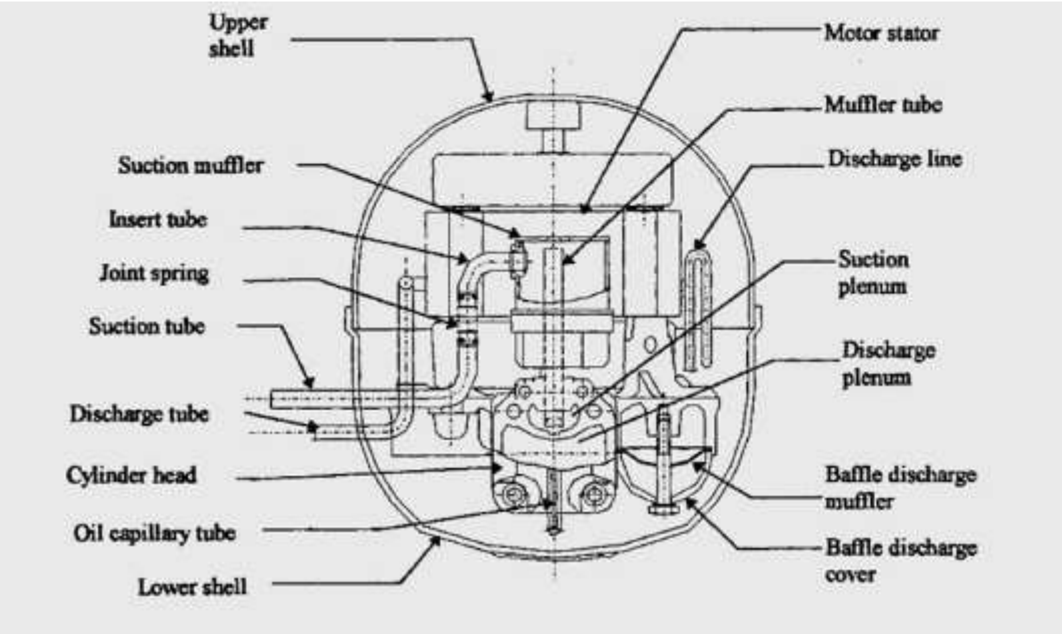


Figure 2.4: Cut-in view of the hermetic compressors

Source: Dincer (2010)

2.5.3 Condenser

The condenser is selected based on the criterion such as the size of the cooling load, refrigerant used, quality and temperature of available cooling water and amount of water that can be circulated. There are three types of condensers utilized in the refrigeration industry. There are water-cooled, air cooled and evaporative condensers. For domestic refrigerator, the air-cooled condensers are the most applicable with a common capacity of 20-120tons. The advantages of air cooled condensers are no water requirement, low installation cost and low maintenance and service requirement (Dincer, 2010).

2.5.4 Capillary Tube

There are many types of throttling devices such as thermostatic expansion valves, constant pressure expansions valves, float valves and capillary tubes. The simplest types of